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INDICATIVE LEVELS OF PM IN THE AMBIENT AIR IN THE SURROUNDING VILLAGES OF THE COPPER SMELTER COMPLEX BOR, SERBIA•

While information on air pollution in the form of particulate matter (PM) has been monitored for a longer period for EU countries, availability of PM data sets in the Western Balkan countries, including the Republic of Serbia, are still limited. Studies related to particulate pollution research have only been carried out in the past several years. The main objective of this paper is to present PM levels measured in the ambient air in the surrounding settlements of the Copper Smelter Complex Bor, as well as a comparison of PM levels in the surrounding settlements with those measured in Bor town. The ambient levels of PM particles (PM_{10}, $PM_{2.5}$) were measured by automatic PM monitors in 4 nearby settlements: Slatina, Oštrelj, Krivelj and Brezonik in the time interval from 2005 to 2010. According to the measurement results, PM_{10} and $PM_{2.5}$ levels in the ambient air were higher in the cold, heating, (October-March) than in the warm no heating period (April-September). Exceeding of the daily limit of PM_{10} and $PM_{2.5}$ mass concentration levels was observed at all measuring points. A higher number of exceedances was detected in the cold period. The results indicate that there is a significant seasonal change in the level of fine particles at all measuring places in surroundings. In addition, the PM levels in Bor are more influenced by the air pollution from the Copper Smelter Complex than the settlements in the vicinity, where the PM concentrations were greatly influenced by the presence of domestic heating in the cold period.

Keywords: air pollution; dust monitoring; particulate matter; correlation; copper.

While a lot of information on PM is available for EU countries, PM data sets in the Western Balkan countries, including the Republic of Serbia, are still limited. Epidemiological studies have associated exposure to particulate matter (PM) with adverse health effects, for example with excesses in daily mortality and morbidity [1-4]. Nowadays, special attention is being paid to indoor air quality, since people spend most of their lifetime indoors. Indoor concentration levels of PM may be attributed to indoor and outdoor sources. Indoor sources include a particle generation related to the combustion processes, interior building materials, using of spray products and other household articles as well as particle re-suspension during intense movement and activity [5,6]. However, besides the different indoor sources, the particles of outdoor origin may penetrate and also contribute significantly to the indoor concentration levels. For human health protection, the EU has introduced limit values for PM_{10} in the ambient air. These limit values were included in the Council Directive 1999/30/EC, later amended by the Council Directive 2008/50/EC, which prescribed a daily limit value of 50 μg/m^3 not to be exceeded more than 35 times per calendar year, and an annual limit value of 40 μg/m^3. The Council Directive 2008/50/EC, on the ambient air quality and cleaner air for Europe established $PM_{2.5}$ thresholds in the am-

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bient air for the first time. The annual average $PM_{2.5}$ level cannot exceed 25 μg/m^3 by 2015. In 2020, the annual average $PM_{2.5}$ limit value will be tightened to 20 μg/m^3, which should be met at all measuring stations [7]. The gravimetric methods are the basis for PM_{10} and $PM_{2.5}$ outdoor monitoring purposes. Besides reference methods, other monitoring techniques, which can provide equivalent results to the reference method, may be used. Automatic on-line dust monitors offer insight into particulate levels in the time series of short intervals (few minutes), which cannot be obtained using the gravimetric methods. In comparison with the automatic monitors, the gravimetric methods are labor-intensive as they require pre/post-conditioning and manual weighing of filters, and therefore are not ideally suited for the routine compliance measurements. However, the techniques, used by the real-time aerosol monitors, differ substantially from validated gravimetric methods and therefore using of these methods requires an investigation of comparability of the methods in measuring PM levels [8-10]. Note that the automatic particulate monitors, such as the light-scattering monitors used in our research, are only able to provide the approximate indoor and outdoor PM mass concentrations, because their measurement principle is not directly related to mass (*i.e.*, an estimate of mass is derived from the optical scattering intensity). The optical scattering efficiency per unit mass is not constant with respect to the particulate size and composition. Therefore, these instruments deliver an accurate PM mass concentration only in the particle size distribution and composition that are not very different from the calibration standard. Biases in the PM exposure estimates may also be due to an incomplete capture of the particle size ranges [10].

Data about air pollution in the Republic of Serbia have been reported to the European Environment Agency operated AirBASE since 2003, but data about particulate matter fractions are still scarce [11]. Monitoring of PM_{10} began in Belgrade city in 2003. In other towns, particulate matter monitoring has been established during the last few years [11]. The Bor Municipality is situated in the eastern part of the Republic of Serbia. Air pollution is perceived as one of the most important environmental problems in wider area of Bor town [11-15]. The dominant air pollution sources are surface mining of copper ore, including re-suspension of dust from mining and flotation tailings, and pyrometallurgical production of copper from sulphide ores. Dust originating from traffic and heating of residential buildings is also present. The main source of air pollution with SO_2, and toxic metals and metalloids in particulate matter is the Copper Smelter Complex Bor, which has been in operation for more than 100 years (shown in Figure 1) [12,13]. Air pollutant con-

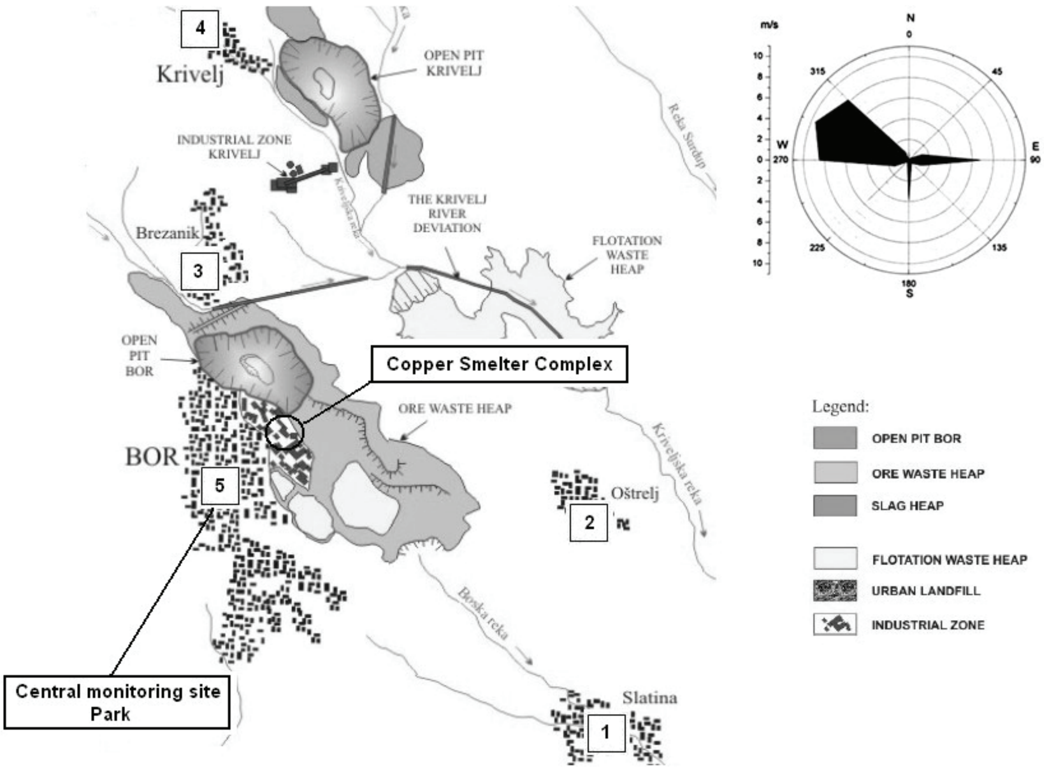

Figure 1. Map of the Bor Municipality area with the marked measuring points (1 Slatina, 2 Oštrelj, 3 Brezonik, 4 Krivelj, 5 Bor - Park), together with the location of the Copper Smelter Complex and wind rose diagram in the period from 2005 to 2010.

centrations in the town and surrounding areas have a close relationship with meteorological parameters and topography [14]. Distribution of pollution substances emitted from the Copper Smelter is strongly influenced by meteorological parameters: wind speed and wind direction [14]. Taking into account the location of the Copper Smelter and dominant wind directions, these pollutants are spread over the Bor town and surrounding areas. The inhabitants of the Bor Municipality are therefore exposed to high levels of air pollution, which can pose serious risks to their health [12,13]. In this study, for the first time, all the available data related to the PM levels in the settlements near Bor were analyzed.

EXPERIMENTAL

Measuring points

The PM levels (PM_{10}, $PM_{2.5}$) were measured in the ambient air of four settlements in surroundings of the Copper Smelter Complex Bor, and in the Bor Town Park, as shown in Figure 1.

Measuring point 1 (Slatina) is located 6 km southeast from the Copper Smelter Complex Bor, downwind of the north and northwest prevailing wind. The PM measurements were conducted at the first floor balcony of the Community Building. The measuring point is located 50 meters from an asphalt road with low traffic intensity (less than 100 vehicles per hour). There are no gravel roads in the immediate vicinity.

Measuring point 2 (Oštrelj) is located 4 km east from the Copper Smelter Complex Bor, downwind of the west and northwest prevailing wind. The PM measurements were conducted at the first floor balcony of the Community Building. The measuring point is located 20 m from an asphalt road with low traffic intensity (less than 50 vehicles per hour). There are no gravel roads in the immediate vicinity.

Measuring point 3 (Brezonik) is located 4 km north from the Copper Smelter Complex Bor. The PM measurements were conducted at the first floor balcony of the Community Building. The measuring point is located 100 m from the asphalt road with low traffic intensity (less than 100 vehicles per hour). There are no gravel roads in the immediate vicinity.

Measuring point 4 (Krivelj) is located 6 km north from the Copper Smelter Complex Bor. The ambient PM measurements were conducted at the first floor balcony of the primary school building. The measurement point is located 50 m from the asphalt road with low traffic intensity (less than 100 vehicles per hour). There are no gravel roads in the immediate vicinity.

Measuring point 5 (Bor – Park) is located 0.6 km west from the Copper Smelter Complex downwind of the east and southeast prevailing wind. The measuring point is located 150 m from the asphalt road with moderate traffic intensity (less than 500 vehicles per hour). There are no gravel roads in the immediate vicinity.

Data collection and instrumentation

Automatic monitoring of the ambient PM pollution is being carried out in the Bor town area since 2003. The measurements are carried out periodically at several measuring places in the town area, using the Turnkey OSIRIS portable device, which serves for the indicative measurements of dust pollution [16]. In the meantime, since 2006, the Serbian Environmental Protection Agency (SEPA) has started monitoring the air pollution with automatic monitors at several sites in the "hot spot" areas. Later, in the framework of the Europe Aid/124394/D/SUP/YU "Supply of Equipment for Air Monitoring" project, SEPA has set up 35 automatic monitoring station, started operating in the last three years. However, spatial coverage of Serbia by the PM monitors is still uneven as the PM monitors are concentrated in Belgrade Metropolitan area and towns in its surroundings [11]. In the summer of 2007, SEPA has set a new monitoring station in Brezonik (marked as 3 in Figure 1). This station contained the Met One Instruments PM_{10} Beta-Attenuation Mass Monitor, BAM 1020 [17]. In May 2009, SEPA has set a new monitoring station in Bor (marked as 5 in Figure 1), with the build-in GRIMM EDM180 dust monitoring system [18].

The results obtained using the 3 automated PM monitors (OSIRIS, BAM-1020 and GRIMM EDM180) in the period from 2005 to 2010 were analyzed in this paper. In the period from 2005 to 2007, an indicative measurement of suspended particles was carried out using the Turnkey OSIRIS monitor, Model 2315, at all measuring points. The monitor gives a continuous and simultaneous indication of Total Suspended Particulate Matter (TSP), PM_{10}, $PM_{2.5}$ and PM_1 mass fractions. It uses a light scattering (diffraction) technique to determine the concentration of airborne dust in the particle size range from about 0.4 to about 20 μm [16]. The measurements have been carried out several times a year, lasting at least 7 days, in order to equally cover the cold and warm periods over the year.

For the most part of the period from 2007 to 2009, the only available automatic PM monitor in operation was BAM-1020, located at the measuring point Brezonik (marked as 3 in Figure 1). This monitor provides the information of PM_{10} levels in the ambient air in the form of hourly average values. The monitor has longstanding U.S. EPA designation as the Federal Equivalent Method (FEM) for continuous PM_{10} particulate monitoring, with lower detection limit (2σ) less than 4.0 μg/m^3 and standard range between 0 and 1000 μg/m^3 [17].

As already stated above, the GRIMM EDM180 dust monitoring system was installed at the measuring point Park (marked as 5 in Figure 1) in 2009. It is the worldwide approved (equivalent with gravimetric method) monitor designed for simultaneous real-time measurement of PM (PM_{10}, $PM_{2.5}$ and PM_1) according to the European Standards EN 12341 (for PM_{10}), and EN 14907 (for $PM_{2.5}$) [18]. It uses a light scattering (90°) technique (reflection) to determine the concentration of airborne dust in the particle size range from about 0.25 to about 32 μm.

Fortunately, it was possible to conduct simultaneous comparison of the PM levels between the majorities of measuring points in the period 2009-2010, when all the available automated monitors were in operation. The monitoring data were originally available as 15-min (OSIRIS) and 1-h averages (BAM-1020 and GRIMM EDM180). For calculation the daily averages, minimum 80% of 15-min and 90% of 1-h averages were required, otherwise the value was considered as the missing one.

Meteorological data for the Bor town urban area are continuously recorded at the meteorological station situated in the Bor Town Park (marked as 5 in Figure 1). This site is located a few hundred meters east of the Copper Smelter Complex Bor. The meteorological data were originally available as 15-min averages.

Calibration factor for OSIRIS particle monitor

In order to more accurately calculate the temporal distribution of PM mass concentrations, the OSIRIS measurements were calibrated as suggested by Ramachandran *et al.* [8]. At each measuring point, during the first week of measurements, a 24-h gravimetric sample was concurrently collected with the OSIRIS monitor measurements. Gravimetric samplers Sven/ /Leckel LVS3 [19] with size-selective inlets for PM_{10} and $PM_{2.5}$ fractions were used for comparative gravimetric measurements. Quartz fiber filters (Whatman QMA 47 mm diameter filters) were used throughout this study for gravimetric sampling. Approximately 15% of all gravimetric samples were exposed as the field blanks The OSIRIS measurements were then scaled using a specific calibration factor for each measuring location:

$$F = \frac{\sum_{i=1}^{n} \frac{G_i}{O_i}}{n} \tag{1}$$

where F is the calibration factor, G_i is the 24-h average gravimetric concentration for the i-th day, O_i is the corresponding 24-h average OSIRIS concentration for the i-th day, and n is the number of days of comparative measurements. The OSIRIS measurements were calibrated with the average aerosol concentration over each 24-h monitoring period. For each 15 min, the average OSIRIS measurement was then multiplied by this calibration factor (which ranged between 1.05 and 1.21 for PM_{10} and between 1.67 and 3.32 for $PM_{2.5}$) to estimate the gravimetric equivalent 15-min average PM concentration.

Quality assurance

Automated PM monitors were operated in accordance with the equipment manual. Diagnostic checks and calibrations were fully followed in according to the recommendations prescribed by the manufacturer. The GRIMM EDM180 flow rate (1.2 dm^3/min) was calibrated by the instrument manufacturer and checked several times during the measurement campaign. The OSIRIS sampler flow rate (0.6 dm^3/min) was calibrated by the instrument manufacturer in the annual maintenance. Accurate measurements using the BAM--1020 monitor were assured with the automatic span check conducted every hour. The LVS3 sampler flow rate (38.3 dm^3/min) was calibrated using the certified flow meter several times during the measurement campaign. Visual inspection of raw data was also carried out. Any suspicious data in the original data set were fully investigated.

RESULTS AND DISCUSSION

Sources of air pollution in Bor

Assessment of total emissions the basic air pollutants from major stationary sources in the municipality of Bor in the period from 2005 to 2010 is shown in Table 1. According to a rough estimate, the major producers of PM emissions are diffusive sources with 65.5% of the all PM emissions. The second place belongs to the major stationary sources with 28%, and the third are mobile sources with 6.5% [20]. The biggest emitter in the major stationary sources is the Copper Smelter Complex Bor. The impact of PM emissions from diffuse and mobile sources in the municipality of Bor is not easy to quantify, as in the case of stationary sources. The majority of dwellings in the urban areas in Bor are connected to the centralized heating system (95%). Heating Plant, located

Table 1. Assessment of total emissions of the basic air pollutants from the major stationary sources in the Bor Municipality (t/year)

Year	SO_x/SO_2	NO_x/NO_2	PM
2005	77894	-	832.7
2006	81032	-	1027.7
2007	89802	83.44	1184.5
2008	75972	79.55	1039.7
2009	-	-	-
2010	85017	72.20	822.0

within the Copper Smelting Complex, uses coal as fuel, the average of 30,000 to 50,000 tons per heating season. The results of measurements have showed that the total PM emissions from the Heating Plant per season amounts 40 to 60 t/year [21]. Based on data, shown in Table 1, and the PM emission estimations, the contribution of the Heating Plant emissions to the PM levels in the urban areas in Bor in the cold period cannot be higher than 10%.

Elevated levels of suspended particulates (PM_{10} and $PM_{2.5}$ fractions) in the cold season can be explained by the higher percentage of time without wind (65%) compared to the warm period of the year (45%) in the observed period 2005-2010 [22].

Temporal and spatial variability in PM levels

The mean concentration levels of PM_{10} and $PM_{2.5}$ are displayed in Figure 2, corresponding to the entire sampling period from 2005 to 2010. Also, the mean concentrations sampled over the years, were determined separately for each season and summarized in Tables 2 and 3.

According to Tables 2 and 3 it is obvious that PM levels in the ambient air were higher during heating period (October-March) than during non-heating (April-September) at all measuring points. Unlike the suburban settlements the town settlements are under the constant influence of emissions from the Copper Smelter Complex Bor. During the heating season,

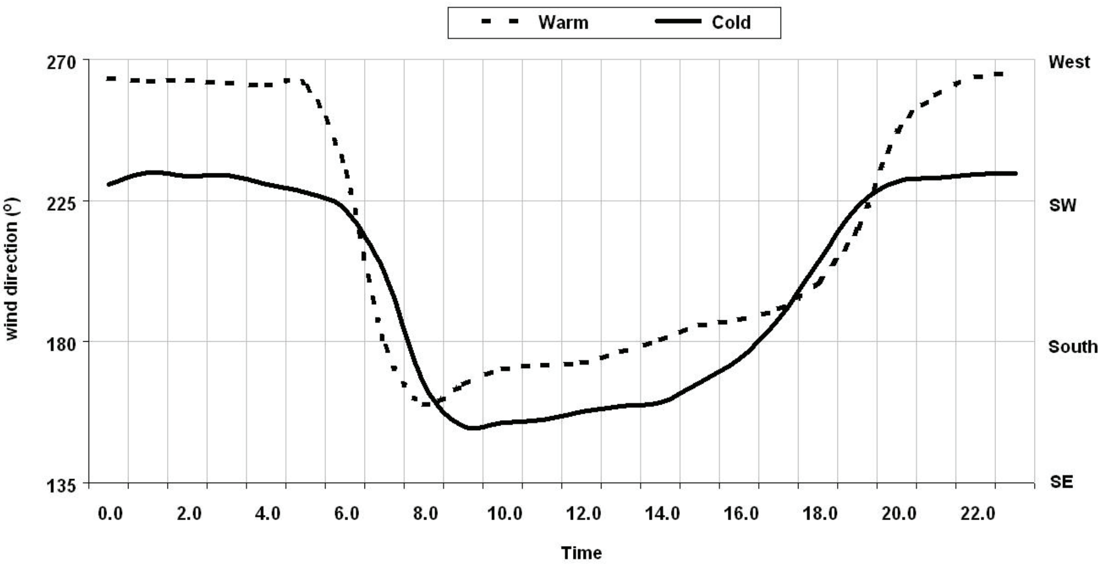

Figure 2. Diurnal time pattern of wind direction at measuring point Park in 2010.

Table 2. Summary statistics for PM_{10} and $PM_{2.5}$ concentrations in the cold periods, expressed in μg/m^3

Monitoring site	PM_{10}			$PM_{2.5}$			Ratio $PM_{2.5}/PM_{10}$	*N*
	Average	Range	SD	Average	Range	SD		
Slatina	38.1	7.2-79.6	22.1	25.5	6.3-56.1	18.2	0.67	30
Oštrelj	25.0	4.7-72.4	15.1	17.1	3.5-58.3	12.3	0.68	49
Brezonik	33.2	8.2-74.9	18.2	21.0	5.9-54.5	15.3	0.70	42
Krivelj	29.1	6.7-54.4	17.2	19.0	6.3-41.1	11.9	0.69	41
Park	39.2	1.9-204.4	33.5	22.1	1.4-97.9	17.7	0.60	196

Table 3. Summary statistics for PM_{10} and $PM_{2.5}$ concentrations in the warm periods, expressed in μg/m^3

Monitoring site	PM_{10}			$PM_{2.5}$			Ratio $PM_{2.5}/PM_{10}$	*N*
	Average	Range	SD	Average	Range	SD		
Slatina	36.9	14.1-76.5	15.4	16.3	8.6-42.9	10.5	0.37	24
Oštrelj	22.0	7.5-43.8	9.5	7.1	2.3-15.0	2.9	0.34	28
Brezonik	30.1	9.4-78.5	18.5	7.3	1.7-16.4	4.7	0.30	24
Krivelj	25.0	17.7-41.8	8.8	6.1	5.1-7.5	1.0	0.34	22
Park	35.0	1.6-138.1	19.8	19.2	1.0-123.7	13.0	0.53	398

there is a noticeable increase of the level of fine particles in the surrounding settlements. It is known that the main cause of this phenomenon is heating of the residential buildings in the suburban and rural areas. Of course, this is not the only possible cause of increase in the PM concentrations, but it is the most apparent, especially in the periods of calm weather with poor ventilation typical for the autumn and winter periods in the Bor Municipality area. The temporal and spatial variability of PM measurements was analyzed aiming to present novel information about the detailed structure of the air quality situation in settlements surrounding the Copper Smelter Complex Bor. The comparisons of hourly averaged PM values at different measuring points in the field campaign, together with the wind directions and speeds were carried out. Strong fluctuations of hourly mean PM levels are mostly related to the changes in wind speed and direction. This phenomenon is typical for conditions with the wind speed less than 2 m/s and wind direction changes that cause detectable air pollution at the measuring points [13,14]. According to the data collected, at measuring point Slatina, the PM levels reached maximum when the winds were blowing from the northwest direction, while at measuring point Brezonik, the peaks of PM levels occur when the winds blow from the southeast direction. Similar to this, at measuring point Park, the PM levels reached maximum when winds were blowing from the east direction, while at measuring point Oštrelj, the peaks of PM levels occurred when the winds were blowing from the west direction. At measuring point Krivelj, the PM levels reached maximum when the winds were blowing from the south and southeast direction.

Daily average PM_{10} levels measured in Bor town and the surrounding settlements appear to be at the same level as in the selected European urban, rural and industrial sites, or even lower [23-26]. According to SEPA annual report for 2010, the average annual PM_{10} levels, measured in Bor (31 μg/m^3), were among the lowest compared with the PM_{10} levels, measured in other Serbian cities [15]. Daily average PM_{10} and $PM_{2.5}$ levels were higher in the cold period compared to the warm period. Fraction of days with PM_{10} concentrations above the daily limit (50 μg/m^3) was within the range from 11% to 25%. Also, the fraction of days with $PM_{2.5}$ concentrations above the WHO daily mean guideline value (25 μg/m^3) [5] was within the range of 10% to 22%. A greater number of levels exceeding the limits was detected in the cold period.

Daily mean $PM_{2.5}/PM_{10}$ concentration ratios

The contribution of fine and coarse particles to PM_{10} can be assessed by observing the daily mean $PM_{2.5}/PM_{10}$ ratios. According to Table 2 and 3, the daily mean $PM_{2.5}/PM_{10}$ ratios were generally higher in the heating periods particularly at the rural sites. Therefore, it can be noted that the daily mean $PM_{2.5}/PM_{10}$ ratios pointed to the seasonal pattern, although there are little differences between the measuring points. In the cold periods, the daily mean $PM_{2.5}/PM_{10}$ ratios were 0.69 in the surrounding settlements and 0.60 in the town. In the warm periods, the daily mean $PM_{2.5}/PM_{10}$ ratios were 0.34 in the surrounding settlements and 0.53 in the town. $PM_{2.5}/PM_{10}$ ratio indicates stronger contribution of the fine particle fraction in the cold season in the ambient air in the surrounding settlements. The daily mean $PM_{2.5}/PM_{10}$ ratios observed in Bor town are similar to those reported for the European and Asian cities (0.4-0.9) [5, 25]. For example, the results obtained for Athens has a similar range in ratios (0.45-0.62), with higher ratios in the cold season [23].

Correlation coefficients between PM fractions

The Pearson correlation coefficient (*r*) was determined for the simultaneously carried out measurements, shown in Tables 4 and 5. According to Table 4, the moderate correlation was observed between the hourly mean PM levels in Oštrelj and Park and between the hourly mean PM levels in Slatina and Park. As it is shown in Table 5, high correlation was observed between the daily mean PM levels in Oštrelj and Park, and moderate correlation was observed between the daily mean PM levels in Slatina and Park. This indicates the existence of a common source (one or several) of PM in town and surrounding villages Oštrelj and Slatina.

Table 4. The Pearson correlation coefficients between hourly mean PM levels at selected sites

Cold period	Park PM_{10}	Park $PM_{2.5}$	Oštrelj PM_{10}	Oštrelj $PM_{2.5}$	Slatina PM_{10}	Slatina $PM_{2.5}$
Park PM_{10}	1					
Park $PM_{2.5}$	0.96	1				
Oštrelj PM_{10}	0.42	0.40	1			
Oštrelj $PM_{2.5}$	0.42	0.42	0.93	1		
Slatina PM_{10}	0.33	0.32	no data	no data	1	
Slatina $PM_{2.5}$	0.33	0.33	no data	no data	0.94	1

Table 5. The Pearson correlation coefficients between daily mean PM levels at selected sites

Cold period	Park PM_{10}	Park $PM_{2.5}$	Oštrelj PM_{10}	Oštrelj $PM_{2.5}$	Slatina PM_{10}	Slatina $PM_{2.5}$
Park PM_{10}	1					
Park $PM_{2.5}$	0.99	1				
Oštrelj PM_{10}	0.65	0.65	1			
Oštrelj $PM_{2.5}$	0.69	0.65	0.96	1		
Slatina PM_{10}	0.38	0.35	no data	no data	1	
Slatina $PM_{2.5}$	0.39	0.38	no data	no data	0.96	1

Diurnal variations of PM_{10} levels

The Municipality of Bor and its surroundings are characterized by continental climate. Due to its position, which is widely open to the Vlaska depression, there is a very strong influence from the east climate. Therefore, the climate characteristics in Bor and its surroundings are often quite different from those prevailing in the other parts of the Republic of Serbia. The climate is continental, which in the highest mountain zones is transformed in the mild mountain climate. The features of such climate are warm and sunny summers and cold winters with a lot of snow [27]. The average diurnal patterns for meteorological parameters of wind speed and wind direction in 2010 are shown in Figures 2 and 3. The diurnal PM_{10} levels pattern is driven by emission characteristics of the dominant sources and the meteorological conditions. Therefore, differences between measuring points as well as seasonal differences are to be expected.

The average diurnal patterns for PM_{10} levels at measuring points Park and Slatina in 2010 are shown in Figures 4 and 5. According to Figure 4, maximum PM_{10} levels at measuring point Park occur in the time intervals from 6:00 AM to 11:00 AM and from 3:00 PM to 8:00 PM. This occurs mostly due to the changes in wind direction from the northwest to the southeast and vice versa. In the time interval from 8:00 AM to 8:00 PM, the average wind speed is 1.5 to 2.8 m/s, which prevents the deposition of dust.

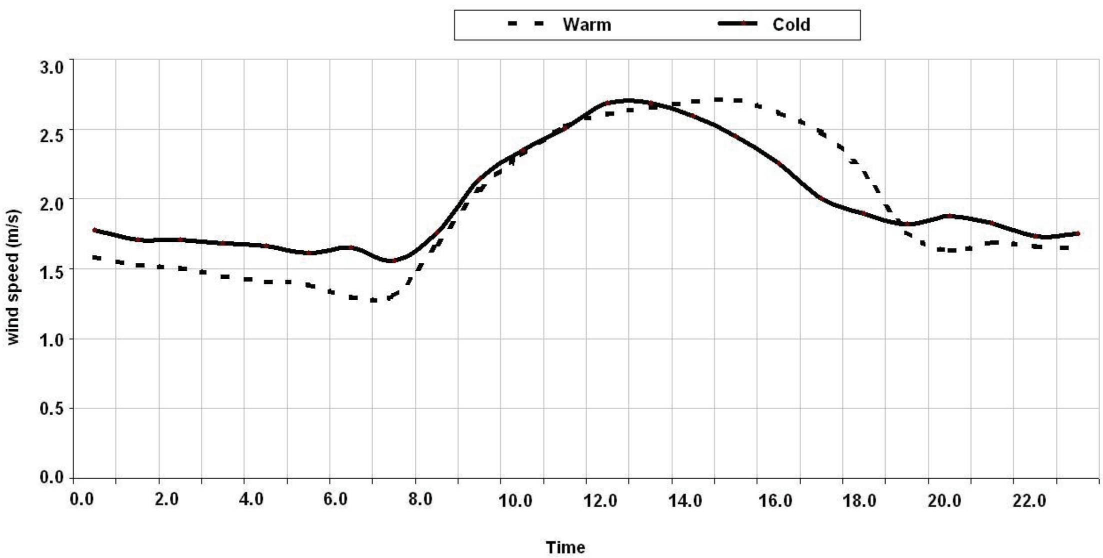

Figure 3. Diurnal time pattern of wind speed at measuring point Park in 2010.

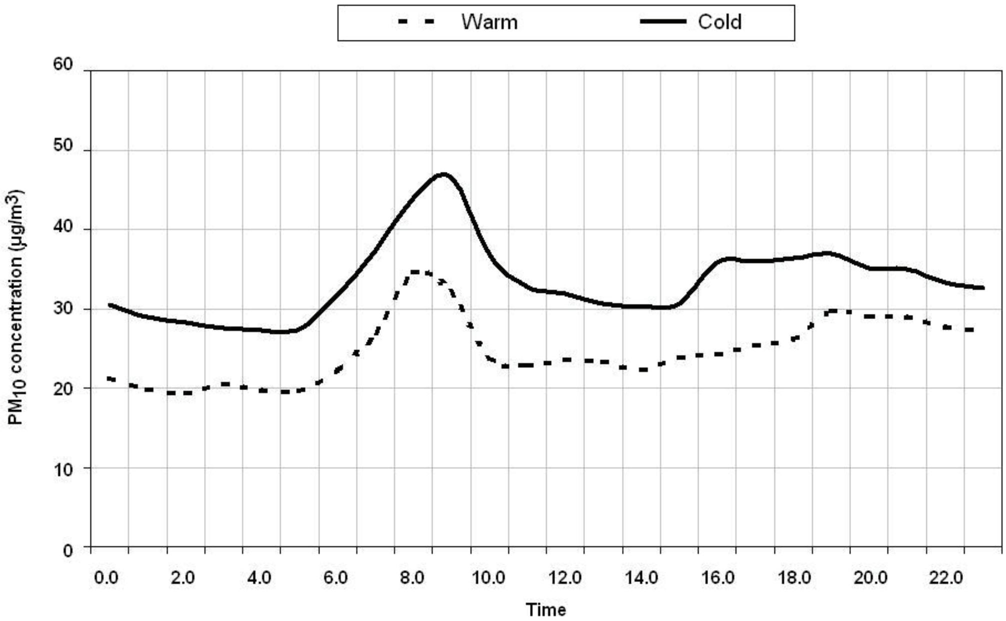

Figure 4. Diurnal time pattern of PM_{10} levels at measuring point Park in 2010.

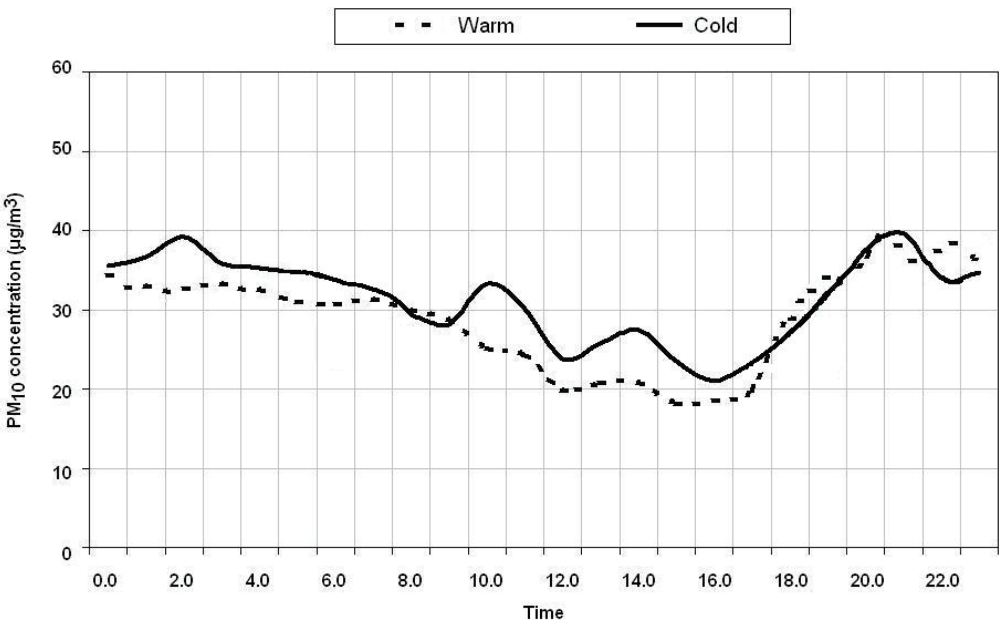

Figure 5. Diurnal time pattern of PM_{10} levels at measuring point Slatina in 2010.

The diurnal pattern of PM_{10} levels for the measuring point Park is basically similar for both warm and cold periods, which suggests that the most important emission sources are seasonally independent. The local heating and calm weather additionally cause somewhat higher concentrations in the cold period. The diurnal patterns at the rural sites Oštrelj and Brezonik are basically similar to the pattern at the town site Park. However, the diurnal pattern at the rural site Slatina is different compared to town site Park; the highest concentrations were reached at different times. According to Figure 5, in warm period at the measureing point Slatina maximal PM_{10} levels occur in the time intervals from midnight to 10:00 AM and from 6:00 PM to midnight. This is directly related to the dominant wind direction at that time of day (west, northwest). PM emitted from the Copper Smelter Complex Bor is carried by the wind to rural villages in the vicinity. All settlements located downwind relative to copper smelter were exposed to air pollution. In cold period maximal PM_{10} levels occur in the same time interval as in warm period. Compared to warm period there are additional increases in PM_{10} levels under the influence of local heating of individual households in the time interval from 10:00 AM to 3:00 PM.

CONCLUSIONS

Temporal and spatial pattern analysis of PM data is important for source identification. The aim of the present study is to characterize PM levels at one urban and four rural sites in the surroundings of the Copper Smelter Complex Bor. The data analysis indicated that PM fractions followed a simultaneous, heavily weather-dependent pattern indicating that the urban as well as the rural environments are dominated by similar emission sources. The strong fluctuations of the hourly mean PM levels are mostly related to the changes in weather conditions (wind speed and direction). This phenomenon is typical for wind speed less than 2 m/s and as well as for the wind direction changes that cause detectable air pollution. The PM_{10} levels at town site were 10% higher in the cold period than in warm period. At rural sites, PM_{10} levels were 11% higher in the cold period than in the warm period. The $PM_{2.5}$ levels at town site were 15% higher in the cold period than in the warm period. At rural sites, $PM_{2.5}$ levels were 148% higher in the cold period than in the warm period. Further, the exceeding of daily limit in case of PM_{10} fraction (50 $\mu g/m^3$) was observed at all measuring points (36 exceeding recorded in 2010 at the urban site Park). Daily mean $PM_{2.5}/PM_{10}$ ratios observed in the rural sites in the cold periods were twice as high as daily mean $PM_{2.5}/PM_{10}$ ratios observed in the warm periods. The differences in PM ratios indicate the significant seasonal changes in the level of fine particles at all measuring points in the rural surroundings. Based on all this, we conclude that PM levels in Bor town are under more influence of the pollution sources originated from the Copper Smelter Complex than the settlements in the vicinity. Also, the villages near the Copper Smelter Complex were greatly influenced by the presence of domestic heating in the cold periods.

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REFERENCES

[1] H.R. Anderson, S.A. Bremner, R.W. Atkinson, R.M. Harrison, S. Walters, Occup. Environ. Med. **58** (2001) 504--510

[2] R.W. Atkinson, G.W. Fuller, H.R. Anderson, R.M. Harrison, B. Armstrong, Epidemiology **21** (2010) 501-511

[3] C.A. Pope III, D.W. Dockery, J. Air Waste Manag. Assoc. **56** (2006) 709-742

[4] C.A. Pope III, R.T. Burnett, D. Krewski, M. Jerrett, Y. Shi, E.E. Calle, Epidemiol. Prev. **120** (2009) 941-948

[5] WHO, Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide: - Global update (2005), http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf (accessed 2 August 2011)

[6] http://www.epa.gov/iaq/pubs/insidestory.html (accessed 2 May 2012)

[7] H. Wolff, L. Perry, Rev. Environ. Econ. Policy **4** (2010) 293-308

[8] G. Ramachandran, J.L. Adgate, G.C. Pratt, K. Sexton, Aerosol Sci. Technol. **37** (2003) 33-45

[9] J.D. Yanosky, P.L. Williams, D.L. MacIntosh, Atmos. Environ. **36** (2002) 107-113.

[10] V. Tasić, M. Jovašević-Stojanović, S. Vardoulakis, N. Milošević, R. Kovačević, J. Petrović, Atmos. Environ. **54** (2012) 358-364

[11] M. Jovašević-Stojanović, A. Bartonova, Chem. Ind. Chem. Eng. Q. **16** (2010) 207−212

[12] M. Dimitrijević, A. Kostov, V. Tasić, N. Milošević, J. Hazard. Mater. **164** (2009) 892-899

[13] S.M. Šerbula, M.M. Antonijević, N.M. Milošević, S.M. Milić, A.A. Ilić, J. Hazard. Mater. **181** (2010) 43-51

[14] V. Tasić, N. Milošević, R. Kovačević, N. Petrović, Chem. Ind. Chem. Eng. Q. **16** (2010) 219−228

[15] SEPA, State of Environment in the Republic of Serbia during 2010 (annual report) http://www.sepa.gov.rs/download/Izvestaj_o_stanju_zivotne_sredine_za_2010_godinu.pdf (accessed 2 May 2012)

[16] Turnkey Instruments: Osiris http://www.turnkey-instruments.com/environment.php?id=8 (Accessed 2 August 2011)

[17] Met One Instruments, Inc. http://www.metone.com/documents/BAM1020_new.pdf (accessed 2 May 2012)

[18] http://www.grimm-aerosol.com/downloads/datasheets/en/ /GrimmAerosolTechnik_Enviro_GeneralCatalogue.pdf (accessed 2 August 2011)

[19] http://www.et.co.uk/docs/LVS3_MVS6%20Product%20Datasheet.pdf (accessed 2 December 2011)

[20] http://www.ekoplan.gov.rs/aqptwinning/training/files/workshop%2005.04.2012/Presentation%20-%20AQP%20Bor.ppt#261,1, (accessed 2 May 2012)

[21] Reports of emissions from stationary sources on the territory of Bor agglomeration in the period 2005-2010, Archives of the Mining and Metallurgy Institute Bor (in Serbian)

[22] Monthly reports about quality of ambient air in the Bor town area in the period 2005-2010, Archives of the Mining and Metallurgy Institute Bor (in Serbian)

[23] A. Chaloulakou, P. Kassomenos, N. Spyrellis, P. Demokritou, P. Koutrakis, Atmos. Environ. **37** (2003) 649-660

[24] M. Tasić, S. Rajšić, V. Novaković, Z. Milijić, M. Tomašević, Physica Scripta T118 (2005) 29-30

[25] F. Sameh, W. Hager, Air Quality Data in 2001. Report Nr. 4/2002, Municipality of Linz, http://www.Linz.at/images/0204WEB.pdf (accessed 2 August 2011)

[26] J. P. Putaud, R. Van Dingenen, A. Alastuey, H. Bauer, W. Birmili, J. Cyrys, H. Flentje, S. Fuzzi, R. Gehrig, H. C. Hansson, R. M. Harrison, H. Herrmann, R. Hitzenberger, C. Hüglin, A. M. Jones, A. Kasper-Giebl, G. Kiss, A. Kousam, T. A. J. Kuhlbusch, G. Löschau, W. Maenhaut, A. Molnar, T. Moreno, J. Pekkanen, C. Perrino, M. Pitz, H. Puxbaum, X. Querol, S. Rodriguez, I. Salma, J. Schwarz, J. Smolik, J. Schneider, G. Spindler, H. Brink, J. Tursic, M. Viana, A. Wiedensohler, F. Raes, Atmos. Environ. **44** (2010) 1308-1320

[27] http://www.rtb.rs/media/dokumenti/nt/EIA_Volume_1.pdf (accessed 2 May 2012).

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NAUČNI RAD

INDIKATIVNI NIVOI FRAKCIJA SUSPENDOVANIH ČESTICA U SELIMA U BLIZINI TOPIONICE BAKRA U BORU, SRBIJA

U zemljama Evropske Unije informacije o aerozagađenju suspendovanim česticama prikupljaju se i dostupne su za duži vremenski period nego u zemljama Zapadnog Balkana, uključujući i Republiku Srbiju. Projekti i studije koje se odnose na istaživanje aerozagađenja suspendovanim česticama intenzivnije se sprovode u Republici Srbiji tek u poslednjih nekoliko godina. Osnovni cilj ovog rada je da se prikažu koncentracije suspendovanih čestica merene u ambijentalnom vazduhu u naseljima u blizini Topionice bakra Bor. Takođe, u radu je prikazano poređenje masenih koncentracija suspendovanih čestica u okolnim naseljima sa koncentracijama izmerenim u Boru, u neposrednoj blizini Topionice bakra. Koncentracije suspendovanih čestica prečnika do 10 i do 2.5 mikrona (PM10, PM2.5), koje su prikazane u radu, merene su automatskim monitorima u seoskim mesnim zajednicama: Slatina, Oštrelj, Krivelj i Brezonik i u gradu Boru (Park) u vremenskom periodu od 2005. do 2010. godine. Izmerene masene koncentracije obeju posmatranih frakcija suspendovanih čestica (PM10 i PM2.5) više su u hladnom periodu (October-March) nego u toplom periodu (april-septembar) godine. Na svim mernim mestima detektovana su prekoračenja dnevnih graničnih vrednosti masenih koncentracija suspendovanih čestica PM10 i PM2.5. Veći broj prekoračenja detektovan je tokom hladnog perioda (u grejnoj sezoni). Uočena je i značajna sezonska promena masenih koncentracija finih čestica (PM2.5) na svim mernim mestima u okolini Topionice bakra. Utvrđeno je i to da aerozagađenje koje potiče iz Topionice bakra više utiče na povećanje nivoa suspendovanih čestica u gradu Boru nego na povećanje nivoa ovih čestica u okolnim naseljima. Na povećanje nivoa suspendovanih čestica u naseljima u blizini Topionice bakra u hladnom periodu godine najviše utiče grejanje objekata za stanovanje.

Ključne reči: monitoring aerozagađenja, frakcije suspendovanih čestica, korelacija, topionica bakra.